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MOMENTUM HARVESTING TECHNIQUES FOR SOLAR SYSTEM TRAVEL

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ABSTRACT

Astronomers are lately estimating there are 400,000 Earth visiting asteroids larger than 100 meters in diameter! These asteroids are uniquely accessible sources of building materials, propellants, oxygen, water and minerals. They also constitute a huge momentum reserve, potentially usable for travel throughout the solar system.

To use this momentum, we must track these stealthy objects, and learn to extract the momentum we want. This paper discusses momentum harvesting by momentum transfer from asteroid to spacecraft, and by using the momentum of the extraterrestrial material to help deliver itself to our destination.

A net and tether concept is the suggested means of asteroid capture, the basic momentum exchange process. The energy damping characteristics of the tether will determine the velocity mismatch that can be tolerated, and hence the amount of momentum that can be harvested per capture. As it plays out of its reel, drag on the tether steadily accelerates the spacecraft.

This paper discusses a variety of concepts for riding and using the asteroid after capture. The hitchhiker uses momentum transfer only. The beachcomber, the caveman, the swinger, the prospector, and the rock wrecker also take advantage of raw asteroidal materials. The chemist and the hijacker go further, they process the asteroid into propellants.

Or, an "asteroid railway system" could evolve with each hijacked asteroid becoming a scheduled train. Travelers could board the space railway system assured that water, oxygen and propellants await them.

THE OPPORTUNITY

Mother Nature has provided an abundance of interplanetary resources for those beings observant enough to see them and wise enough to use them. Earth visiting asteroids provide material wealth in a uniquely useful place, near Earth yet beyond the depths of its gravity well. Too small and too dark to be easily seen, we are discovering lately that Earth-visiting asteroids are numerous, not rare.

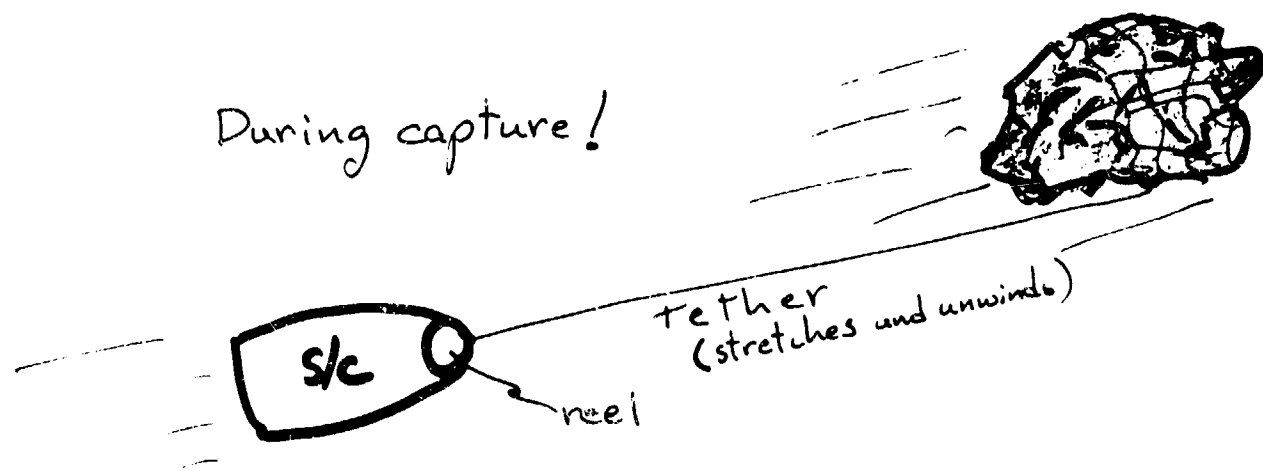
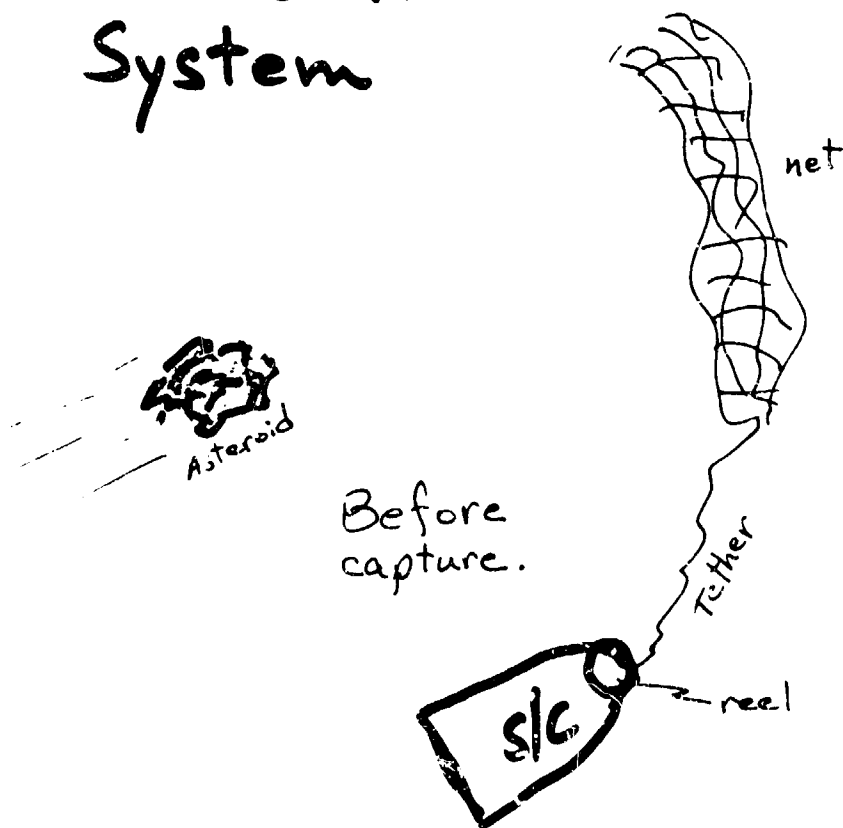
To quote the enthusiasm in The SERC Newsletter of December 1989 from the NASA/University of Arizona Space Engineering Research Center:

"Observations such as those made by ... the University of Arizona and ... JPL ... suggest that there are 1000 to 2000 kilometer-sized near-Earth asteroids, and roughly 400,000 larger than 100 meters in diameter. ... we can begin to build confidence that life-support, building, shielding, and propellant materials will be available where and when we need them."

And, momentum is an asteroidal resource also worth harvesting! There are two aspects to momentum harvesting. First, select bulk extraterrestrial mass which already has favorable momentum for its delivery to a desired destination. For example, select asteroids with low return delta velocities as sources of material in earth-lunar space. Second, exchange momentum from these fast flying natural objects to our spacecraft.

Their great numbers means there may indeed be an asteroid "going our way" where and when we need it. To really use these flying fragments of fine fortune, we must first track these stealthy objects, then learn to extract the momentum we want.

Net + Tether System



John Lewis, a planetary resources expert at the University of Arizona, observes that current technology can be deployed to find and track earth crossing asteroids, as well to deflect, destroy or use them. His book, SPACE RESOURCES Breaking the Bonds of Earth, is strongly recommended. The concepts described here add the conjectured possibility of catching rides on asteroids, to further enhance the already great opportunities Lewis has identified.

NET AND TETHER CAPTURE APPARATUS

The challenge of momentum exchange is to dilute, in time, hypervelocity collisions to the point where they become constructive interactions. A net and tether concept is suggested as a fundamental means of asteroid capture.

The net and tether isolates the collision from the spacecraft. The net must be designed to survive by virtue of low mass, great strength and prudent pre-acceleration. The tether should have large energy damping characteristics, acting as one very long sequence of dash pots, to prevent whiplash and "yo-yoing". The state-of-the-art of energy absorption technology will determine the amount of velocity mismatch that can be tolerated, and hence the amount of momentum that can be harvested in a single capture. What we can accomplish depends, quite literally, on how far we can stretch the technology.

As it plays out of its reel, drag on the tether steadily accelerates the spacecraft. It's vital to remove the initial angular momentum. If this isn't accomplished by tangential drag, then it must be completed by propulsion or by using a third body.

Many applications are possible after asteroid capture. Some options are described qualitatively.

THE BEACHCOMBER

The beachcomber opportunistically

harvests the bounty of small asteroids washed his way by the celestial tides. As he snags the small asteroids in his nets, he incrementally gathers both momentum and useful materials.

Since he gathers small stuff, the beachcomber cannot expect much help from the asteroid tracking network. But he has many mini-asteroids he can harvest, so he is not very dependent on chance. He must selectively harvest the asteroids going his way. Just as earthly beachcombers carry metal detectors to discover their best finds, the space beachcomber will likely carry his own detection and tracking system, too. It will provide him reaction time to see and catch asteroids flying in his preferred direction.

THE HITCHHIKER

The hitchhiker hangs onto an asteroid until his desired velocity is reached. He then releases the tether system, either by severing the tether or by disengaging the entire mechanism. By using a few net-tether devices, he can hitch a series of rides.

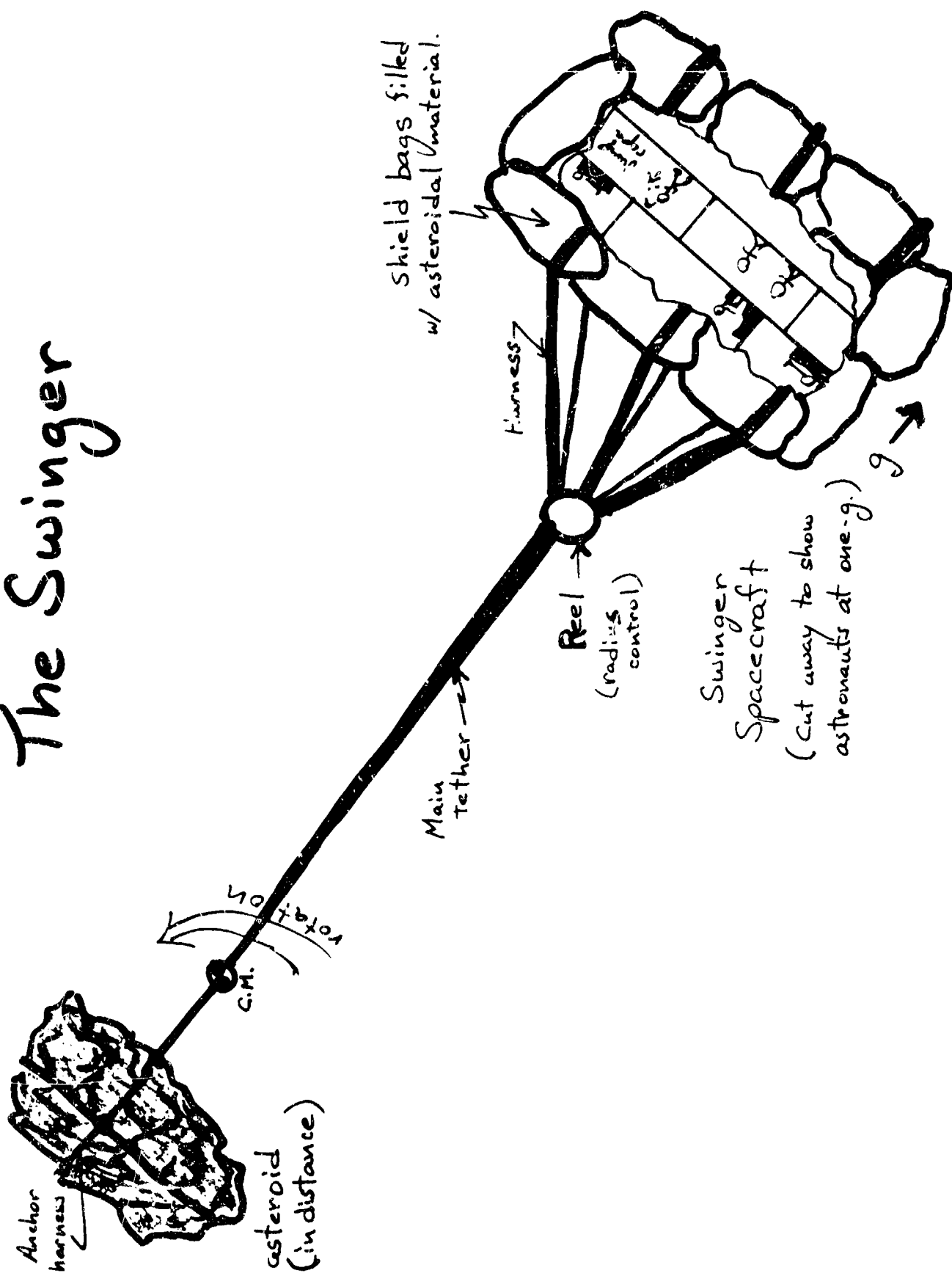
The hitchhiker uses ordinary propulsion to perform course correction, to reach his desired destination at just the right moment. Small early corrections can easily make significant changes at destination.

Prior cataloging of earth visiting asteroids or a complete active deep space tracking network will be vital to hitchhikers, so their rides out and their returns home will not be left to chance.

THE CAVEMAN

The caveman seeks shelter from cosmic rays and solar flares. After his tether plays out and he has reached equal velocity with the asteroid, he reels in the tether and climbs aboard. It is relatively easy for him to burrow into most

The Swinger



asteroids.

Once inside, the caveman has better protection from highly penetrating cosmic radiation than any other space traveler, and solar flares are of absolutely no consequence. The other comforts of home? They need some planning and preparation.

THE SWINGER

The swinger also wants the benefits of gravity during his ride through the solar system. After pulling himself aboard the asteroid, he pulverizes as much material as he needs and stuffs this free shielding into expandable compartments on the exterior of his craft. The swinger then pushes off and plays out his tether. At a selected distance he stops the tether, then thrusts tangentially to create gravity.

Earthly gravity is his most logical choice, but any g-level is possible from centrifugal force. If sturdy anchor ground cannot be found, the swinger can tie up the asteroid like a package, to prevent unplanned separation. The initial asteroid spin rate and tether moment arms must be taken into account to prevent the swinger from getting wound around the axle, so to speak. Despinning the asteroid or tether play out are possible solutions.

The clever swinger can pick up more free velocity in any direction by playing with angular momentum. A small velocity at a very long radius will change to a much larger velocity as the tether is shortened. A well timed tether cut will send the swinger off on the next leg of his journey, with his free cargo of shield and raw materials.

THE PROSPECTOR

The prospector wants big profits with little work. He gathers and sells raw asteroid materials.

The prospector knows that each earth visiting asteroid has a low

delta velocity to somewhere in the inner solar system. Each such destination is one of his orbital marketplaces. His tanks are salvaged from the jetsam of others. He stuffs all the empty tanks he can tug with asteroidal matter, chunked or ground for best packing.

After selling his raw materials at the most convenient market, he buys his needed propellant right there from the processors. This propellant is now quite cheap, thanks to his supplying inexpensive feedstock.

In response to market prices, some prospectors may pass up asteroids of opportunity to wait for richer mineral-bearing asteroids heading toward high profit ports, such as Earth.

THE CHEMIST

The chemist is a bit more enterprising than the prospector. Rather than transport heavy, bulky raw materials, she sets up propellant production plants right there on the asteroid.

These plants give her all the propellant she needs to ship her finished products to easily accessible orbital markets. These products include not only fuels and oxygen, but also water and other precious chemicals not available from the Moon. She can greatly underprice her competitors shipping from Earth, Mars or the Moon.

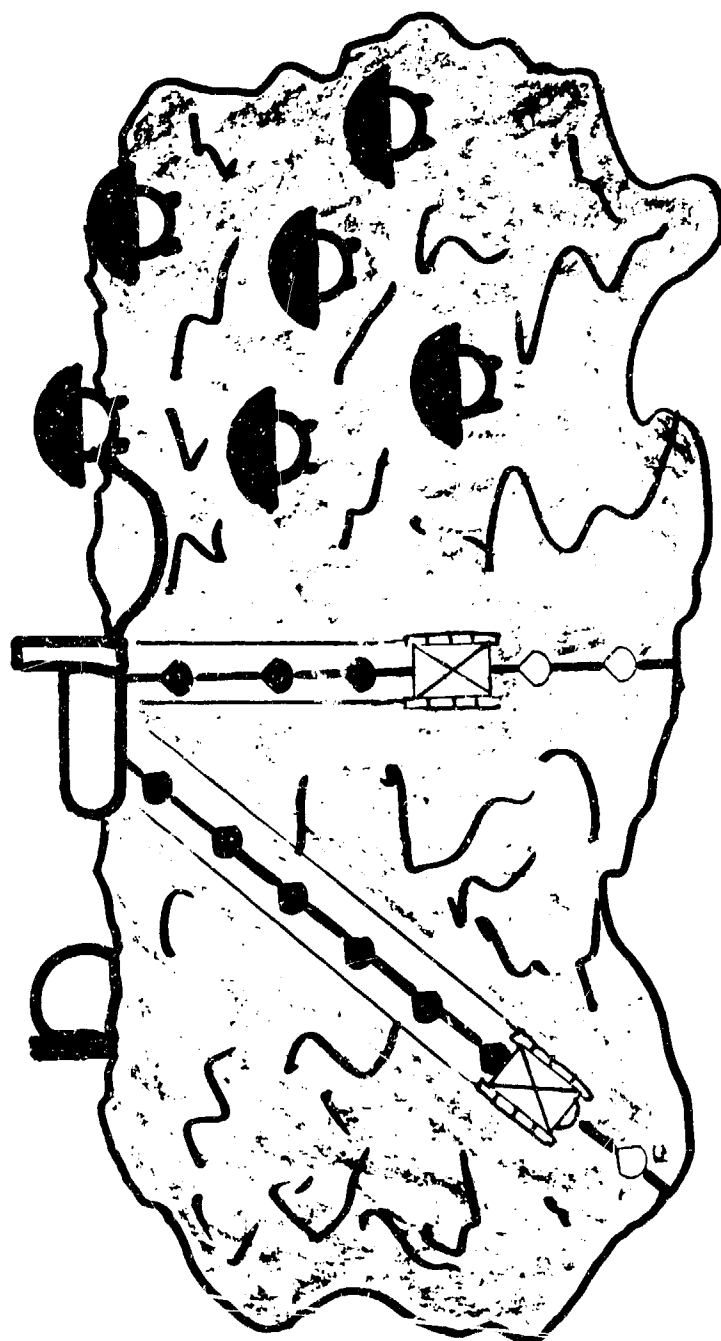
Nuclear power gives the chemist her high production rates and high profits. Automation and electric propulsion will make her future operations even more profitable.

THE ROCK WRECKER




The rock wrecker is a gatherer and seller of raw materials, but with much grander ambitions than the prospector. She delivers huge chunks of asteroid, intact!

After reeling in her tether and boarding an asteroid, the rock

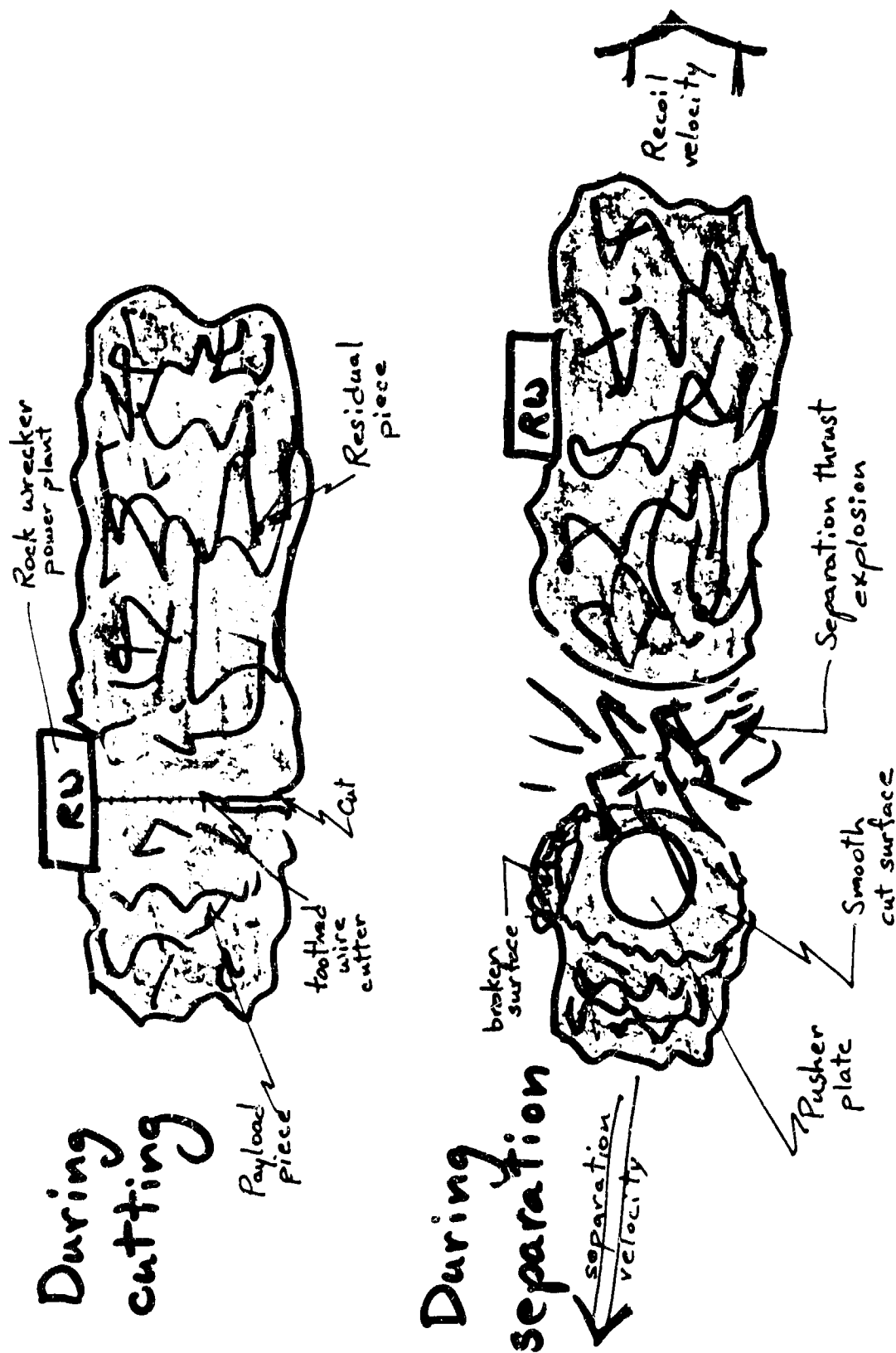
The Chemist



 Trench miner
(tether following)
  Empty ore bucket
  Loaded ore bucket

 Power plant
  Propellant plant
  Space Tanker
(w/ aerobrake)

The Rock Wrecker



wrecker sets about slicing off as large a chunk as she can deliver to market. By keeping it intact, she avoids the limitations of tankage. Through use of a long toothed wire cable, slicing is not too difficult. The challenge is geometric, rather than material toughness.

Delivering the payload piece takes clever application of Newton's third law. The residual asteroid acts as the reaction mass for conservation of momentum, thus avoiding the need for large quantities of propellant. By choosing the relative size and orientation of the pieces at separation, the rock wrecker selects just where the pieces go. The payload goes to market. The residual piece may go to a better orbit for later rock wrecking.

The pieces must not drift apart before full separation thrust is applied. One trick is to not fully sever the asteroid. The separation thrust can be a long steady push, or an explosive force. Pusher plates prevent the pieces from shattering.

THE HIJACKER

Hijackers are not content with tanks of raw material, tanks of propellant, or even large chunks of asteroid. Hijackers take whole asteroids!

One readily envisioned hijacker is a nuclear powered propellant plant combined with a nuclear thermal rocket. Propellant would be produced steady state, then burned in short bursts to adjust the asteroid's orbit. Perihelion burns would adjust aphelion, and vice versa. Other burns could adjust eccentricity and inclination.

Multiple burns are needed at each point. Each hijacking is a long term operation, requiring many orbits and many years. Astronauts could set up the system, during a trip to Mars for example, then let the automated system do its job. The trip to set up the hijacker can be free, or even

profitable, since momentum is harvested and resources can be gathered during this detour. Hijacking jobs would eliminate wasted time, and even boredom, while traveling back and forth through the solar system.

Hijacked asteroids could be destined for planetary capture (assisted by aerobraking) and orbital consumption. Asteroids in orbit would give Earth the same advantage as Mars, which has Phobos and Deimos as ready sources of orbital consumables.

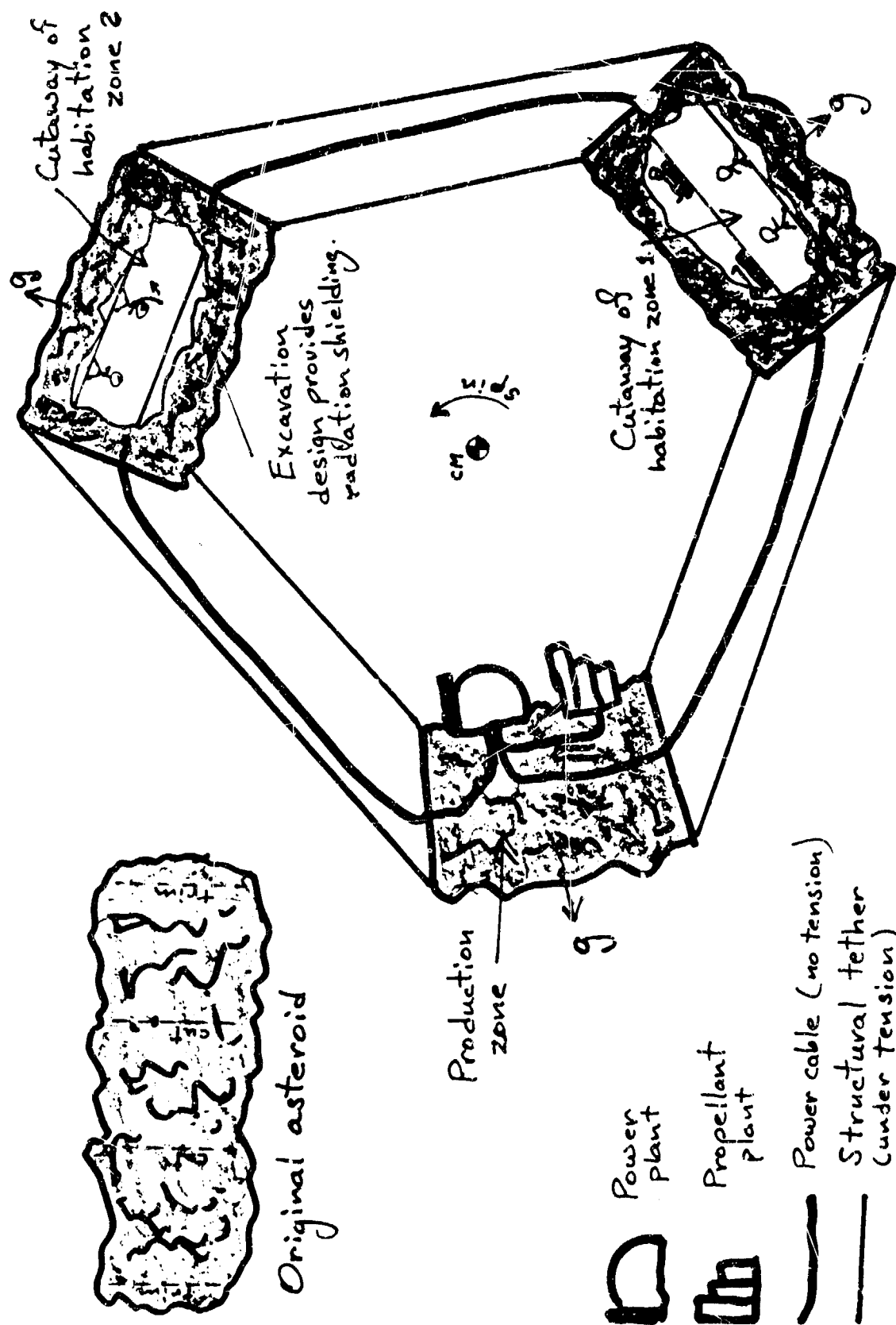
ASTEROID RAILWAY SYSTEM

Perhaps even easier and better than total asteroid consumption may be the development of an "asteroid railway system". Each hijacked asteroid becomes a regularly scheduled "train" linking specific parts of solar system. The railway system evolves to provide more and more frequent travel opportunities as each link is added.

This space railway network would have the advantages of cycling spacecraft, but could be made more robust by use of natural resources, i.e. the asteroids. Space travelers could use lightweight craft to board and exit the railway system, because of assurances that shielding and supplies of water, oxygen and propellants await them. Momentum harvesting while boarding is an added benefit.

Asteroids could be improved by entrepreneurs. A luxury liner may consist of sliced asteroid pieces, rejoined by tethers, then spun up gently to provide safe, habitable compartments complete with earthly gravity. This cruiser would be a product of the hijacker, rock wrecker, caveman, chemist and swinger. The austerities of pioneer space travel would give way to creature comforts and luxuries, all with a speed and economy impossible without nature's gift of earth visiting asteroids.

Small Cruiser on Asteroid Railway



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